

<https://doi.org/10.11646/zootaxa.4521.2.10>  
<http://zoobank.org/urn:lsid:zoobank.org:pub:E6E130FC-811D-4C91-8A42-786634108E17>

## Diversity of saproxylic dance flies and long-legged flies (Diptera: Empidoidea) in a temperate deciduous forest in Quebec, Canada

JEFFREY M. CUMMING<sup>1</sup>, BRADLEY J. SINCLAIR<sup>2</sup>, SCOTT E. BROOKS<sup>1</sup>, JULIA MLYNAREK<sup>3</sup> & TERRY A. WHEELER<sup>†</sup>

<sup>1</sup>Invertebrate Biodiversity, Agriculture and Agri-Food Canada, K.W. Neatby Bldg., C.E.F., 960 Carling Ave., Ottawa, ON, Canada K1A 0C6. E-mail: jeff.cumming@canada.ca, scott.brooks@canada.ca

<sup>2</sup>Canadian National Collection of Insects and Ottawa Plant Laboratory—Entomology, CFIA, K.W. Neatby Bldg., C.E.F., 960 Carling Ave., Ottawa, ON, Canada K1A 0C6. E-mail: bradley.sinclair@canada.ca

<sup>3</sup>Agriculture and Agri-Food Canada, Harrow Research and Development Centre, Harrow, ON, Canada N0R 1G0  
E-mail: julia.mlynarek@canada.ca

<sup>†</sup>Deceased, formerly with Department of Natural Resource Sciences, McGill University, Macdonald Campus, Ste-Anne-de-Bellevue, QC, Canada

### Abstract

A large diversity of saproxylic Empidoidea from a temperate deciduous forest in southern Quebec is documented. Adults of 43 empidoid species representing 19 genera in 12 subfamilies and three families were collected from *in situ* sealed emergence traps placed over decayed logs of American beech (*Fagus grandifolia* Ehrhart) and sugar maple (*Acer saccharum* Marshall). The results of this technique give a clear indication of the saproxylic larval and pupal habitat of these species. The importance of Empidoidea as larval predators in decayed wood niches is noted.

**Key words:** Dolichopodidae, Empididae, Hybotidae, emergence trap, American beech, sugar maple, larval habitat

### Introduction

The Empidoidea are a large, diverse lineage of flies that include five to eight families depending on the classification scheme followed (e.g., Sinclair & Cumming 2006; Pape *et al.* 2011; Marshall 2012; Wahlberg & Johanson 2018). In terms of diversity the three largest families are the Dolichopodidae, Empididae and Hybotidae. As a group, adult Empidoidea are primarily predaceous flies, with many flower visiting taxa feeding on nectar or pollen (Ulrich 2005; Sinclair & Cumming 2006). However, the habits of immature Empidoidea are poorly known, with the larvae of a few groups (e.g., the empidid subfamilies Clinocerinae and Hemerodromiinae) being mainly aquatic (Dyte 1967), whereas most others are terrestrial, occurring in forests, grasslands and agricultural fields, or are associated with various semi-aquatic habitats (e.g., edges of ponds, bogs, marshes, fens, etc.) (Cumming & Sinclair 2008; Pollet & Brooks 2008). For recent summaries on what is known about immature Empidoidea, see Grichanov & Brooks (2017) for Dolichopodidae, Sinclair & Daugeron (2017) for Empididae, and Sinclair & Cumming (2017) for Hybotidae.

In comparison with the aquatic empidoid groups, little has been published about the immature stages of the terrestrial groups, including their habits and the ecological niches they occupy. In general, terrestrial larvae are mainly considered to be predators of various arthropods in moist soils, with occasional additional records from other substrates such as dung, fungi, under bark, or in rotten wood (Dyte 1959; Smith 1989; Cumming & Cooper 1993; Meyer 2005). The prey items consumed by empidoid larvae are usually thought to be primarily larvae of other Diptera (Smith 1969; Cumming & Cooper 1993), but do vary depending upon habitat type (e.g., scolytid beetle larvae under bark preyed on by larvae of the dolichopodid genus *Medetera* Fischer von Waldheim) (Bickel 1985).

Recently there has been considerable interest in the composition of saproxylic Diptera communities and their

role in the ecology of forest ecosystems (Ulyshen 2018). The objective of this paper is to document the diversity of saproxylic empidoid taxa in a temperate deciduous forest in southern Quebec, which were collected from *in situ* sealed emergence traps placed over logs of two hardwood tree species (sugar maple and American beech) in two stages of decay (early and advanced). Association of these adult flies with decaying wood is a clear indication of the larval and pupal habitat of each species. Additional correlated ecological information associated with particular empidoid taxa and log type is also discussed.

## Material and methods

The empidoid samples were collected along with other saproxylic Diptera at the Mont Saint-Hilaire Biosphere Reserve in southern Quebec, Canada ( $45^{\circ}32'40''N$ ,  $73^{\circ}9'5''W$ ) within 500 m of the shore of Lac Hertel at the Reserve between 173 and 223 m elevation, as outlined by Selby (2005) and Mlynarek *et al.* (2018). The Reserve is dominated by old growth, closed canopy hardwood forest made up primarily of sugar maple (*Acer saccharum* Marshall) and American beech (*Fagus grandifolia* Ehrhart), with some oaks (*Quercus* spp.), other maples (*Acer* spp.), birch (*Betula* spp.) and basswood (*Tilia americana* L.).

Specimens of saproxylic Empidoidea were collected in emergence traps placed over fallen logs of sugar maple and American beech, the dominant trees at the Reserve. In May 2004, a total of 20 decaying fallen logs were selected by Selby (2005), with half being sugar maple and half being American beech. For each tree species five logs were selected that were in an early decay stage (approximately two years after tree death) and five logs were selected that were in an advanced decay stage (approximately six years after tree death). The sampling protocol used by Selby (2005) is further described in Mlynarek *et al.* (2018). All the fallen logs were between 18 and 22 cm in diameter and were cut to 1.2 m in length. They were free of soil, not immersed in water, and all were branchless. Each log was then repositioned in its original location on a plastic ground sheet and covered by an emergence trap (with collecting head) that was sealed to the ground sheet. Samples were collected from the collecting heads once a week for 16 weeks from 3 June to 16 September, 2004, which corresponds to the main period of Diptera activity in this region.

The empidoid specimens were identified to species using available literature (e.g., Bickel 2009; Robinson 1964; Melander 1928; Steyskal & Knutson 1981) and through comparison with the compressive Empidoidea collection of the Canadian National Collection of Insects (CNC) in Ottawa, Ontario. Specimens identified only to morpho-species and not given proper species names are a consequence of genera still needing major revision for the Nearctic Region. Voucher specimens were deposited in the Lyman Entomological Museum (LEMQ) of McGill University (Ste-Anne-de-Bellevue, Quebec).

## Results

This study accumulated a large diversity of saproxylic Empidoidea from a temperate deciduous forest in southern Quebec. A total of 43 empidoid species representing 19 genera in 12 subfamilies and three families were collected from sealed emergence traps placed over decaying wood (Table 1).

## Discussion

As part of an earlier inventory of Brachyceran Diptera at the Mont Saint-Hilaire Biosphere Reserve in southern Quebec using Malaise, trunk and yellow pan traps, Fast & Wheeler (2004) documented 67 species of Empidoidea. Direct species comparisons are not possible with the saproxylic Empidoidea recorded here, because most of the species listed by Fast & Wheeler (2004) were only identified to morpho-species, and direct habitat associations could not be inferred from the passive trapping methods they employed. However, 14 of the empidoid genera collected here were shared with the 25 empidoid genera (56%) listed by Fast & Wheeler (2004). This suggests that although several empidoid taxa found in this temperate deciduous forest appear to be saproxylic, many others are probably not and may live as immatures in different niches such as moist soils, or semi-aquatic and aquatic habitats.

Nevertheless, of importance here is the large diversity of empidoid taxa recorded as saproxylic (43 species in 19 genera, representing 12 different subfamilies and three families). Only a few European studies (*i.e.*, Hövemeyer 1998; Rotheray *et al.* 2001; Meyer & Nötzold 2004; Meyer 2005) have reported a modest diversity of Empidoidea with saproxylic larvae. However, the association of adult empidoid taxa (collected using emergence traps and photoeklectors) with their immature stages being strictly in decaying wood, is not as compelling in most of these studies as it is in the present study, because associated soil and fungi were not completely isolated from the decaying wood substrates (*e.g.*, mainly stumps and woody litter). The 21 species of Empidoidea belonging to 12 genera, reported by Hövemeyer & Schauermann (2003) in their list of 163 species of Diptera collected in a decomposition study of dead beech wood in Germany, is the most comparable survey to date.

In North America only the supplemental lists of saproxylic Diptera reported by Work & Hibbert (2011) and Mlynarek *et al.* (2018) also include empidoid taxa. Using *in situ* emergence traps, Work & Hibbert (2011) studied the effects of two biomass harvesting scenarios in mixedwood forest stands (mainly aspen, *Populus tremuloides* Michaux, and black spruce, *Picea mariana* (Miller)) on saproxylic Diptera diversity in western Quebec. In their supplemental list of 222 saproxylic Diptera species, 28 species and 15 genera of Empidoidea were recorded, of which eight genera (53%) are shared in the list presented here (Table 1). The empidoid taxa included in the supplemental list of saproxylic Diptera reported on by Mlynarek *et al.* (2018) is basically comparable to the list presented in Table 1, but includes some misidentifications and errors in morpho-species sorting. That ecological study, which focused on various Diptera community assemblages in decaying sugar maple and American beech wood, is based on the same samples collected by Selby (2005) and reported on here.

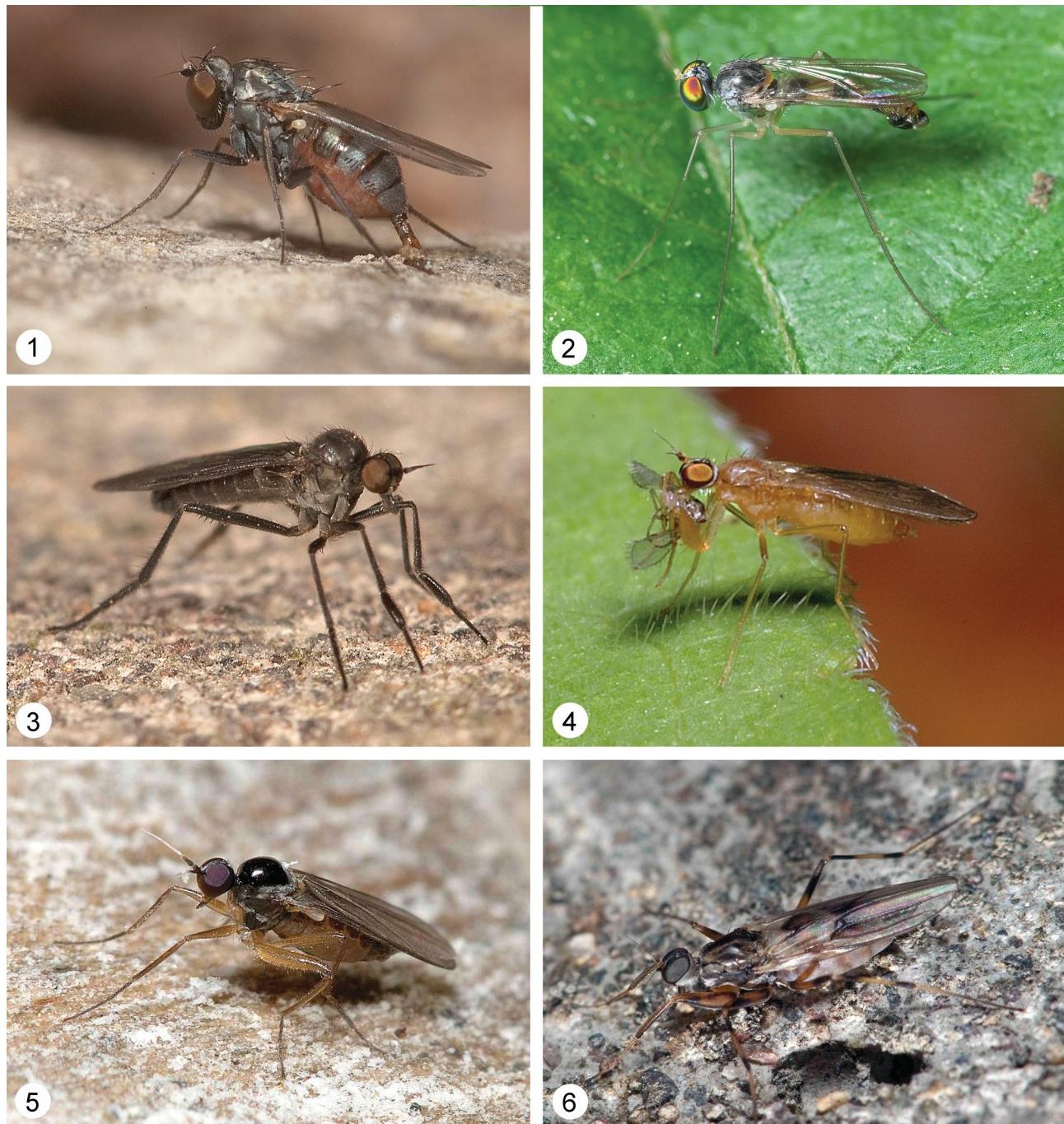
The empidoid species listed in Table 1 are all generally considered to be forest dwelling species that could potentially have their immature stages in decaying wood. The dolichopodid genera *Medetera* (Fig. 1) and *Neurigona* Rondani (Fig. 2) in particular, are both found on tree trunks as adults, and certain *Medetera* larvae have been found on decaying sap (Rotheray *et al.* 2001), or are well known as predators of scolytid beetle larvae in galleries under bark (Bickel 1985). Habits of the immature stages of the other dolichopodid taxa listed in Table 1 are unknown, but adults of *Gymnopternus* Loew, *Chrysotimus* Loew, *Sympycnus* Loew and *Xanthochlorus* Loew are commonly collected in woodlands, so it is not too surprising that these genera may include saproxylic species.

Although most of the empidid species listed in Table 1 are forest dwelling species that could be expected to be saproxylic, the two species of *Chelipoda* Macquart (Fig. 4) belong to the subfamily Hemerodromiinae, which is generally considered to be a group with aquatic larvae (Dyte 1967). The only known exception among hemerodromiines is the terrestrial larva of the Palaearctic species *Phyllodromia melanocephala* Fabricius collected in moist humus under beech trees (Trehen 1969). Immatures of *Chelipoda* are not known, but Harper (1980) has indicated they are probably aquatic, based on records of a few adult specimens taken from emergence traps placed over small streams in Quebec. However, the two saproxylic *Chelipoda* species listed here suggest that immatures of the genus are not necessarily aquatic as has been previously assumed, but may be found in more terrestrial habitats such as dead wood and moist soils. Likewise the immature stages of *Hilara* are also poorly known. Most species are forest dwelling (Fig. 3) and adult flies hunt (or scavenge dead) insects from water surfaces where they form large swarms and mating aggregations (Plant 2004). However, Smith (1989) and Plant (2004) indicate on the basis of a few ecological studies that larval and pupal development in *Hilara* generally occurs in terrestrial soils, which are often remote from water bodies where mating activity occurs. The occurrence of the six species of saproxylic *Hilara* found in this study, substantiates this observation.

Like other Empidoidea, the immature stages of Hybotidae are also poorly known. Larvae have been sporadically recorded from moist soil, dung and rotten wood, among other terrestrial habitats (Sinclair & Cumming 2017). The numerous hybotid species listed in Table 1 are all forest dwelling species (Figs 5, 6) that might be expected to have their immature stages in decaying wood. *Oedalea* larvae have been recorded by Stark (2008) as saproxylic and Chillcott & Teskey (1983) mention that a specimen of *Megagrapha pubescens* (Loew) was reared from a decaying elm (*Ulmus* sp.). In addition, adults of *Tachypeza* (Fig. 6) are generally found on tree trunks, which in itself strongly suggests that their larvae and pupae are saproxylic. Interestingly the single undescribed species of *Trichinomyia* listed here, belongs to a genus previously recorded only from the Palaearctic Region. The listing here is the first published record of *Trichinomyia* from the Nearctic Region (also supplementally recorded in Mlynarek *et al.* 2018, based on identification by JMC & BJS).

Mlynarek *et al.* (2018) studied the various Diptera community assemblages in early and advanced decayed sugar maple and American beech, using the same samples collected by Selby (2005). Their ecological study dealt with four Diptera larval feeding guilds in the decayed wood (*i.e.*, fungivores, saprophages, predators and parasitoids), with the Empidoidea representing the entire predaceous feeding guild. Certain species in their fungivorous and saprophagous larval feeding guilds were significantly correlated with one tree species and/or decay type. However, all the empidoid species listed here in Table 1 that seem restricted to a combination of one

tree species and/or one decay type are likely to appear that way as a result of small sample size ( $\leq 12$  specimens collected). In contrast, the two empidoid species, *Allodromia testacea* and *Tachypeza fenestrata*, with the largest sample sizes (112 and 100 specimens, respectively) were found in logs of both tree species and in both decay types, although Mlynarek *et al.* (2018) reported on a statistically significant association with advanced decay in both species. We suspect that the predaceous feeding guild represented by all the Empidoidea species reported on here, may be less restricted to decay type and log species than at least some of the fungivorous and saprophagous species analyzed by Mlynarek *et al.* (2018).



**FIGURES 1–6.** Photographs of Nearctic species of forest dwelling Empidoidea taken by Stephen Marshall. **1.** Dolichopodidae, *Medetera* sp., female ovipositing on a tree. **2.** Dolichopodidae, *Neurigona* sp., male. **3.** Empididae, *Hilara* sp., male. **4.** Empididae, *Chelipoda* sp., female with prey. **5.** Hybotidae, *Platypalpus* sp. (albiseta group), female. **6.** Hybotidae, *Tachypeza* sp., female.

**TABLE 1.** Southern Quebec saproxylic species of Empidoidea showing rearing associations with tree species and log decay stage.

Family	Subfamily	Species	Tree species (Beech/ Maple)	Decay stage (Early/ Advanced)
Dolichopodidae				
	Dolichopodinae	<i>Gymnopterus subulatus</i> Loew	Beech	Early
		<i>Gymnopterus</i> sp. 1	Maple	Early
		<i>Gymnopterus</i> sp. 2	Maple	Early
	Medeterinae	<i>Medetera apicalis</i> (Zetterstedt)	Both	Both
		<i>Medetera veles</i> Loew	Both	Both
		<i>Medetera vittata</i> Van Duzee	Beech	Early
		<i>Medetera petulca</i> group sp. 1	Beech	Early
	Neurigoninae	<i>Neurigona arcuata</i> Van Duzee	Both	Advanced
		<i>Neurigona deformis</i> van Duzee	Both	Both
	Peloropeodinae	<i>Chrysotimus</i> sp. 1	Both	Both
		<i>Chrysotimus</i> sp. 2	Beech	Advanced
	Sympycninae	<i>Sympycnus lineatus</i> Loew	Both	Advanced
	Xanthochlorinae	<i>Xanthochlorus helvinus</i> Loew	Both	Both
Empididae				
	Empidinae	<i>Empis poeciloptera</i> Loew	Beech	Early
		<i>Hilara</i> sp. 1	Both	Both
		<i>Hilara</i> sp. 2	Beech	Both
		<i>Hilara</i> sp. 3	Beech	Advanced
		<i>Hilara</i> sp. 4	Both	Early
		<i>Hilara</i> sp. 5	Both	Both
		<i>Hilara</i> sp. 6	Beech	Early
		<i>Rhamphomyia polita</i> group sp. 9	Maple	Early
		<i>Rhamphomyia pusio</i> Loew	Beech	Advanced
		<i>Rhamphomyia soleata</i> Melander	Both	Both
		<i>Rhamphomyia umblicata</i> Loew	Both	Both
		<i>Rhamphomyia</i> sp. 1	Beech	Advanced
	Hemerodromiinae	<i>Chelipoda americana</i> (Melander)	Beech	Advanced
		<i>Chelipoda elongata</i> (Melander)	Maple	Early
Hybotidae				
	Ocydromiinae	<i>Leptopeza compta</i> Coquillett	Beech	Early
		<i>Leptopeza flavipes</i> (Meigen)	Beech	Advanced
	Oedaleinae	<i>Euthyneura bucinator</i> Melander	Both	Both
		<i>Oedalea ohioensis</i> Melander	Maple	Advanced
		<i>Oedelea pruinosa</i> Coquillett	Beech	Advanced
	Tachydromiinae	<i>Allodromia testacea</i> (Melander)	Both	Both
		<i>Drapetis</i> sp. 1	Maple	Advanced
		<i>Drapetis</i> sp. 2	Both	Both
		<i>Megagrapha platytarsis</i> Chillcott	Both	Both
		<i>Platypalpus harpiger</i> Melander	Both	Both
		<i>Platypalpus holosericus</i> Melander	Both	Both

.....continued on the next page

**TABLE 1.** (Continued)

Family	Subfamily	Species	Tree species (Beech/ Maple)	Decay stage (Early/ Advanced)
Trichininae	Trichininae	<i>Platypalpus</i> sp. 1	Maple	Both
		<i>Platypalpus</i> sp. 2	Beech	Early
		<i>Tachypeza excisa</i> Melander	Beech	Advanced
		<i>Tachypeza fenestrata</i> (Say)	Both	Both
		<i>Trichinomyia</i> sp. 1	Maple	Early

The diversity of saproxylic empidoid taxa documented in this paper indicates that decaying wood found in deciduous temperate forests is an important ecological niche for the immature stages of the superfamily. Generally it has been assumed that larvae of Empidoidea are most commonly found in aquatic, semi-aquatic, or moist soil habitats. Clearly the saproxylic nature of many members of this superfamily needs to be more intensively investigated. For example, some of the empidoid taxa listed in Table 1 may be facultatively saproxylic (e.g., *Chelipoda*, *Hilara*) whereas others may be obligate saproxylics (e.g., *Oedalea*, *Tachypeza*), but such information is not currently known. The study of the immature stages of Empidoidea, including their prey and habitat preferences, is still in its infancy. Further studies such as this one, using sealed emergence traps placed over decaying logs as well as other techniques, can be expected to reveal important additional discoveries about this diverse group of forest dwelling predators.

### Acknowledgements

We thank Duncan Selby, whose M.Sc. (McGill University) project on saproxylic gall midge diversity provided the Empidoidea specimens for this study. Stéphanie Boucher (LEMQ) kindly arranged for the loan of specimens. Stephen Marshall (University of Guelph) generously provided the digital photographs of Empidoidea reproduced in this paper. Adrian Plant (Mahasarakham University) provided a constructive peer-review of the manuscript that substantially improved the paper. The research was supported in part by a Natural Sciences and Engineering Research Council of Canada Discovery Grant to TAW.

### References

- Bickel, D.J. (1985) A revision of the Nearctic *Medetera* (Diptera: Dolichopodidae). *United States Department of Agriculture, Technical Bulletin*, No. 1692, 1–109.
- Bickel, D.J. (2009) Dolichopodidae (long-legged flies). In: Brown, B.V., Borkent, A., Cumming, J.M., Wood, D.M., Woodley, N.E. & Zumbado, M.A. (Eds.), *Manual of Central American Diptera. Vol. 1*. NRC Research Press, Ottawa, Ontario, pp. 671–694.
- Chillcott, J.G. & Teskey, H.J. (1983) A revision of the New World genera allied to *Megagrapha* Melander (Diptera: Empididae). *The Canadian Entomologist*, 115, 1291–1328.  
<https://doi.org/10.4039/Ent1151291-10>
- Cumming, J.M. & Cooper, B.E. (1993) Techniques for obtaining adult-associated immature stages of predaceous tachydromiine flies (Diptera: Empidoidea), with implications for rearing and biocontrol. *Entomological News*, 104, 93–101.
- Cumming, J.M. & Sinclair, B.J. (2008) Dance flies, balloon flies, predaceous flies (Diptera: Empidoidea, exclusive of Dolichopodidae). In: Capinera, J.L. (Ed.), *Encyclopedia of Entomology. Vols. 1–4. 2<sup>nd</sup> Edition*. Springer, pp. 1146–1150.  
[https://doi.org/10.1007/978-1-4020-6359-6\\_825](https://doi.org/10.1007/978-1-4020-6359-6_825)
- Dyte, C.E. (1959) Some interesting habits of larval Dolichopodidae (Diptera). *Entomologist's Monthly Magazine*, 95, 139–143.
- Dyte, C.E. (1967) Some distinctions between the larvae and pupae of the Empididae and Dolichopodidae (Diptera). *Proceedings of the Royal Entomological Society of London*, Series A, 42, 119–128.  
<https://doi.org/10.1111/j.1365-3032.1967.tb01011.x>
- Fast, E. & Wheeler, T.A. (2004) Faunal inventory of Brachycera (Diptera) in an old growth forest at Mont Saint-Hilaire, Quebec. *Fabreries*, 29, 1–15.
- Grichanov, I.Y. & Brooks, S.E. (2017) [Chapter] 56. Dolichopodidae (long-legged dance flies). In: Kirk-Spriggs, A.H. & Sinclair, B.J. (Eds.), *Manual of Afrotropical Diptera. Volume 2. Nematocerous Diptera and lower Brachycera*. Suricata 5, South African National Biodiversity Institute, Pretoria, pp. 1265–1320.
- Harper, P.P. (1980) Phenology and distribution of aquatic dance flies (Diptera: Empididae) in a Laurentian watershed. *The*

- American Midland Naturalist*, 104, 110–117.  
<https://doi.org/10.2307/2424964>
- Hövemeyer, K. (1998) Diptera associated with dead beech wood. *Studia dipterologica*, 5, 113–122.
- Hövemeyer, K. & Schauermann, J. (2003) Succession of Diptera on dead beech wood: A 10-year study. *Pedobiologia*, 47, 61–75.  
<https://doi.org/10.1078/0031-4056-00170>
- Marshall, S.A. (2012) *Flies: The Natural History and Diversity of Diptera*. Firefly Books, Richmond Hill, Ontario, 616 pp.
- Melander, A.L. (1928) Diptera, Family Empididae. In: Wytsman, P. (Ed.), *Genera Insectorum*, 185, 1–434.
- Meyer, H. (2005) Langbein-, Tanz- und Schwebfliegen (Diptera: Empidoidea: Dolichopodidae, Empididae, Hybotidae; Syrphidae) im Totholz von Laubwäldern Schleswig-Holsteins. *Faunistisch-Ökologische Mitteilungen*, 8, 363–382.
- Meyer, H. & Nötzold, R. (2004) Besiedlung von Totholz durch Langbein- und Tanzfliegen (Diptera: Empidoidea: Dolichopodidae, Empididae, Hybotidae) in einer halboffenen Weidelandschaft. *Mitteilungen der Deutschen Gesellschaft für Allgemeine und Angewandte Entomologie*, 14, 241–244.
- Mlynarek, J., Grégoire Taillefer, A. & Wheeler, T.A. (2018) Saproxylic Diptera assemblages in a temperate deciduous forest: implications for community assembly. *PeerJ Preprints*, 6, e27034v1.  
<https://doi.org/10.7287/peerj.preprints.27034v1>
- Pape, T., Blagoderov, V. & Mostovski, M.B. (2011) Order DIPTERA Linnaeus, 1758. In: Zhang, Z.-Q. (Ed.), *Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness*. *Zootaxa*, 3148, 222–229.
- Plant, A.R. (2004) *Hilara* Meigen (Diptera: Empididae) in Britain: a provisional synopsis of distribution, habitat preferences and behavior. *Acta Universitatis Carolinae Biologica*, 48, 165–196.
- Pollet, M.A.A. & Brooks, S.E. (2008) Long-legged flies (Diptera: Dolichopodidae). In: Capinera, J.L. (Ed.), *Encyclopedia of Entomology. Vols. 1–4. 2<sup>nd</sup> Edition*. Springer, pp. 2232–2241.
- Robinson, H. (1964) A synopsis of the Dolichopodidae (Diptera) of the southeastern United States and adjacent regions. *Miscellaneous Publications of the Entomological Society of America*, 4, 105–192.
- Rotheray, G.E., Hancock, G., Hewitt, S., Horsfield, D., MacGowan, I., Robertson, D. & Watt, K. (2001) The biodiversity and conservation of saproxylic Diptera in Scotland. *Journal of Insect Conservation*, 5, 77–85.  
<https://doi.org/10.1023/A:1011329722100>
- Selby, R.D. (2005) Diversity of saproxylic Cecidomyiidae (Diptera) in a Quebec hardwood forest. MSc thesis, McGill University, Montreal, xii + 93 pp.
- Sinclair, B.J. & Cumming, J.M. (2006) The morphology, higher-level phylogeny and classification of the Empidoidea (Diptera). *Zootaxa*, 1180, 1–172.
- Sinclair, B.J. & Daugeron, C. (2017) [Chapter] 51. Empididae (empidid dance flies or balloon flies). In: Kirk-Spriggs, A.H. & Sinclair, B.J. (Eds.), *Manual of Afrotropical Diptera. Volume. 2. Nematocerous Diptera and lower Brachycera. Suricata 5*. South African National Biodiversity Institute, Pretoria, pp. 1221–1235.
- Sinclair, B.J. & Cumming, J.M. (2017) [Chapter] 52. Hybotidae (hybotid dance flies). In: Kirk-Spriggs, A.H. & Sinclair, B.J. (Eds.), *Manual of Afrotropical Diptera. Volume 2. Nematocerous Diptera and lower Brachycera. Suricata 5*. South African National Biodiversity Institute, Pretoria, pp. 1237–1250.
- Smith, K.G.V. (1969) The Empididae of southern Africa (Diptera). *Annals of the Natal Museum*, 19, 1–342.
- Smith, K.G.V. (1989) An introduction to the immature stages of British flies. Diptera larvae, with notes on eggs, puparia and pupae. *Handbook for the Identification of British Insects*, 10 (Part 14), 1–280.
- Stark, A. (2008) Species of the genus *Oedalea* Meigen, 1820 (Diptera: Hybotidae): An element of the canopy fauna in European forests? In: Floren, A. & Schmidl, J. (Eds.), *Canopy Arthropod Research in Europe*. Bioform Entomology, Nuremberg, pp. 105–117.
- Steyskal, G.C. & Knutson, L.V. (1981) Empididae. [Chapter] 47. In: McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., & Wood, D.M. (Coords.), *Manual of Nearctic Diptera*, 1, Agriculture Canada Monograph 27, pp. 607–624.
- Trehen, P. (1969) Description des stades préimaginaux et données sur la biologie de *Phyllodromia melanocephala* Fabricius, 1794 (Dipteres-Empididae). *Revue d'Ecologie et de Biologie du Sol*, 6, 41–52.
- Ulrich, H. (2005) Predation by adult Dolichopodidae (Diptera): a review of literature with an annotated prey-predator list. *Studia dipterologica*, 11 (2), 369–403. [2004]
- Ulyshen, M.D. (2018) Saproxylic Diptera. In: Ulyshen, M.D. (Ed.), *Saproxylic Insects*, Zoological Monographs, 1, pp. 167–192.  
[https://doi.org/10.1007/978-3-319-75937-1\\_5](https://doi.org/10.1007/978-3-319-75937-1_5)
- Wahlberg, E. & Johanson, K.A. (2018) Molecular phylogenetics reveals novel relationships within Empidoidea (Diptera). *Systematic Entomology*, 43, 619–636.  
<https://doi.org/10.1111/syen.12297>
- Work, T.T. & Hibbert, A. (2011) Estimating species loss of saproxylic insects under scenarios of reduced coarse woody material in eastern boreal forests. *Ecosphere*, 2, art 41.  
<https://doi.org/10.1890/ES10-00075.1>

© Her Majesty the Queen in Right of Canada, as represented by the Minister of Agriculture and Agri-Food Canada.